Advanced Beam-Dynamics Simulation Tools for the RIA Driver Linac

Part 2: Superconducting Linac

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Benefits of Parallel Beam Dynamics Simulation

- Faster turn-around time
  - ability to ask “what if” questions and optimize design
- Improved physics
  - more *realistic* treatment of phenomena and *simultaneous* treatment of multiple phenomena
  - Self-consistent modeling
  - Fully 3D
- Higher accuracy
  - reduced particle sampling error in particle distribution → high statistics beam loss estimates

Our RIA SC linac modeling rests on a firm foundation: IMPACT code

- IMPACT = Integrated Map and Particle Accelerator Tracking code
- Most widely used parallel linac modeling code in the world
- Has been used to model
  - SNS linac
  - CERN SPL
  - KEK JPARC linac
  - LANL/LEDA beam halo experiment
  - Fundamental studies of intense beams (in collaboration w/ physicists at GSI and CERN)

Main Features of IMPACT

- Parallel Particle-In-Cell (PIC) beam dynamics code
- 2 particle-advance algorithms (map based; Lorentz force)
- Large collection of beamline elements
- Acceleration via rf cavity fields
- 3D space-charge w/ several boundary conditions
- Actually a code suite:
  - ENV3D: 3D envelope code including acceleration
  - THETA: design code
  - IMPACT: parallel PIC code

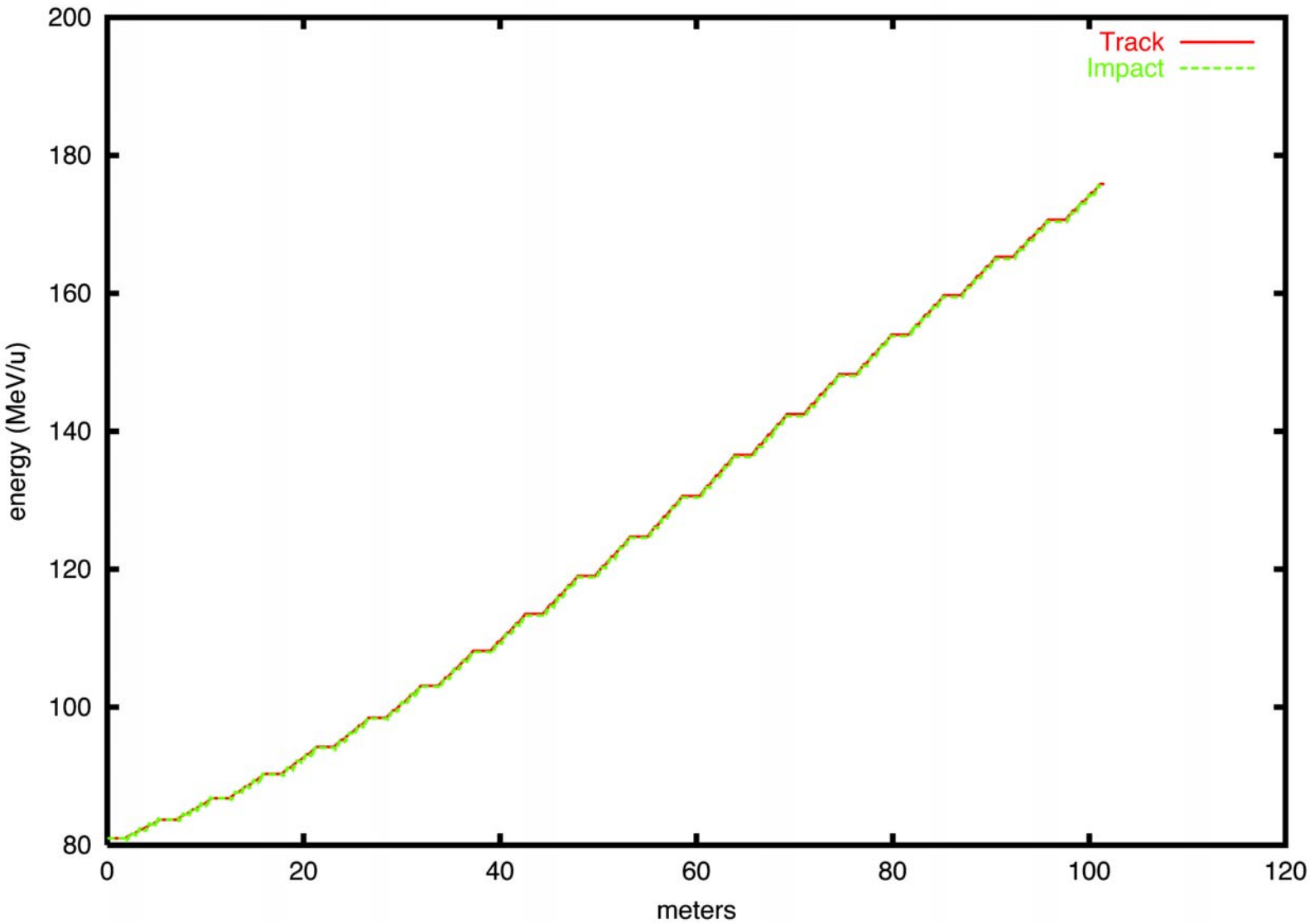
Plan for RIA version of IMPACT

- Code enhancements:
  - Introduce multi-charge capability
  - Introduce bending magnets
  - Incorporate stripping modules
- Benchmarking
  - Comparison with TRACK (ANL) and LANA (MSU)

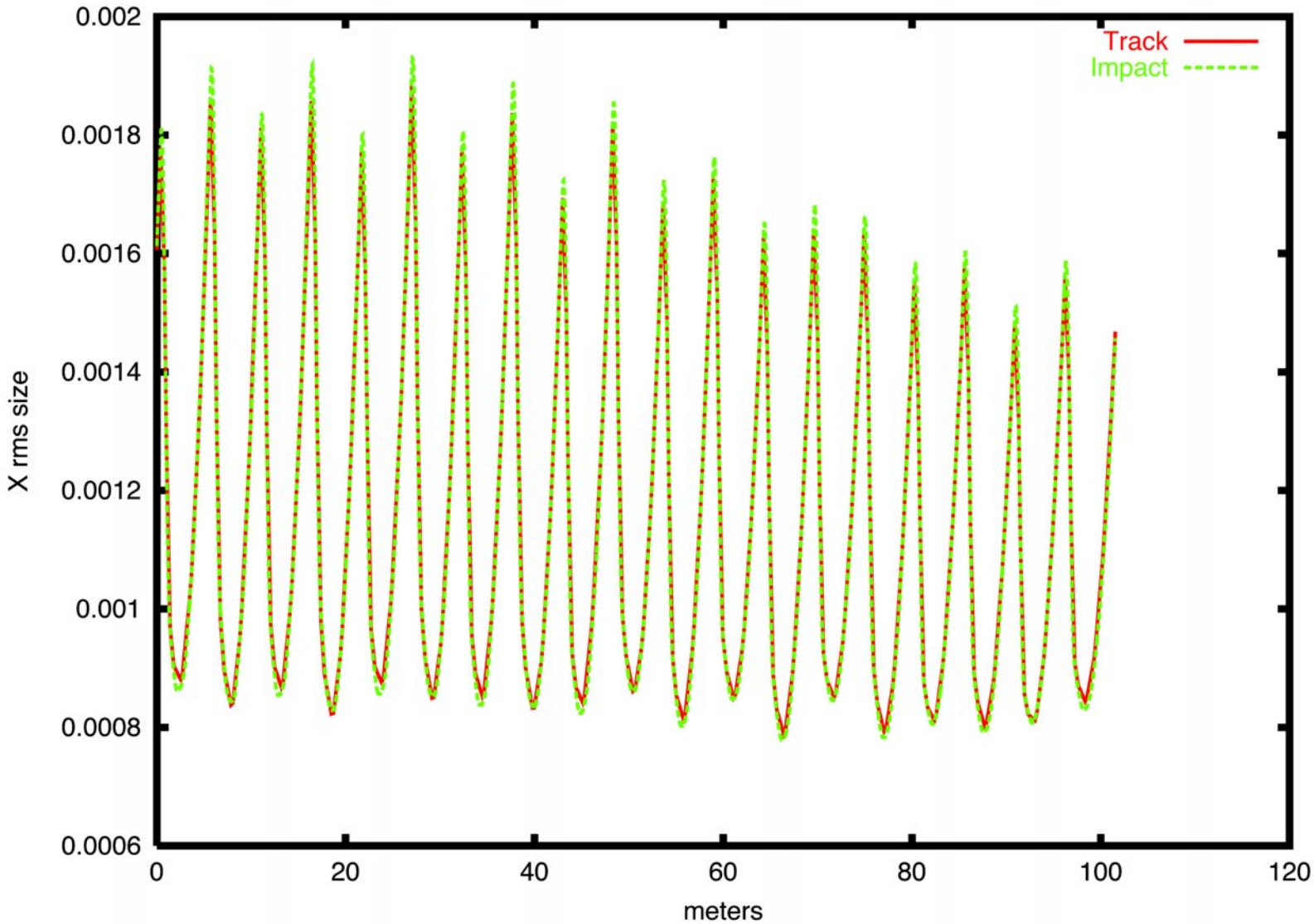
Status of RIA-IMPACT work

- ✓ Multi-charge state capability incorporated and tested
  - Particle tracking, diagnostics
- Benchmarking against TRACK underway
  - energy gain, rms values
- Initial studies of beam loss predictions
- Initial implementation of bending magnets

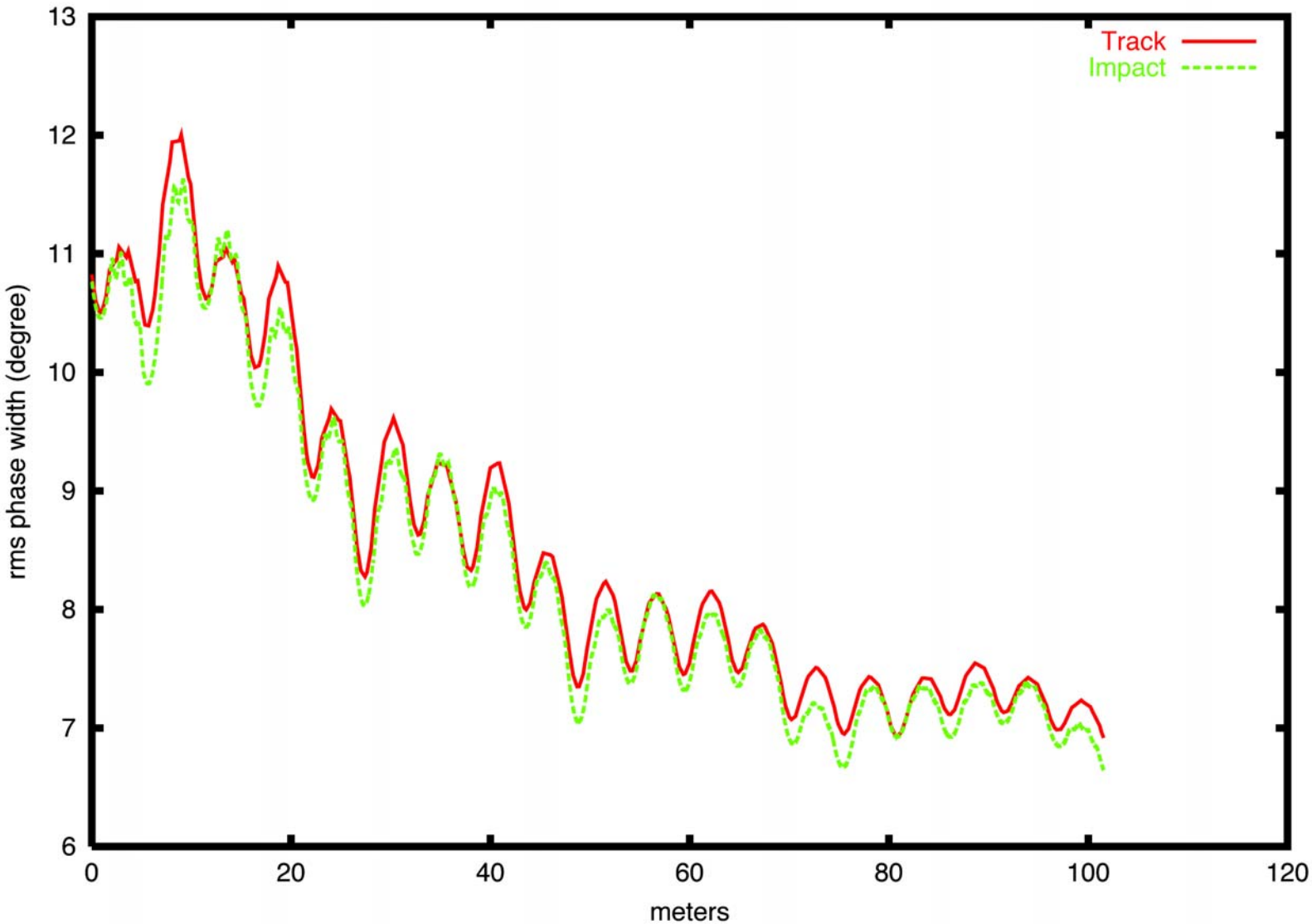
IMPACT simulation through a portion of the high-β linac (81-177 MeV); comparison w/ TRACK



Horizontal rms beam size



Longitudinal rms beam size



Convergence of loss prediction w/ increasing number of simulation particles

- Performed IMPACT simulations using
  - 64K, 640K, 6.4M, 64M particles
  - each initialized w/ 3 different random seeds
- Low variability (~10%) at 6.4M particles

# of particles	Ave. fractional loss (ppm)	#lost Seed1	#lost Seed2	#lost Seed3
64K	20.	2	0	2
640K	10.9	4	9	8
6.4M	13.6	81	97	83
64M	13.3	844	863	848

Importance of end-to-end modeling

- IMPACT simulations with different particle distributions (Waterbag, Gaussian) exhibit losses that are strongly dependent on initial distribution
  - 100M particle Waterbag from 81-177 MeV loses 13 ppm
  - 100M particle Gaussian w/ same rms size loses 3000 ppm
- Prediction of losses will require linking Parmteq and IMPACT in a single end-to-end simulation capability

Scalability test shows almost perfect speedup of IMPACT for RIA simulations

- Performed 10M particle IMPACT simulation through 16 cavities (81-94 MeV) of the RIA linac using
  - 32, 64, 128, 256 processors

# of processors	Execution time (sec)
32	2576
64	1234
128	619
256	326

Full linac simulation (~20x the # of steps compared with the scalability test) would require approximately 100 minutes on 256 processors, or only 50 minutes with 5 million macroparticles

Future Plans

1. Continue comparisons with TRACK and LANA
2. Test bending magnet implementation
3. Work with ANL and MSU to develop and incorporate stripping models; benchmark models against experiment
4. Develop interface to parallel version of Parmteq for combined Parmteq/IMPACT simulations
5. Add new capabilities as specified by RIA design team, e.g.
   - improved modeling of steering
   - optimizer for matching across transitions in the linac
6. Assist with simulations, including error studies, to optimize the RIA design

Summary

- As part of a RIA end-to-end code development effort, IMPACT is being enhanced to meet the needs of the RIA project
- Parallel simulation results (see Table in this talk) and analytical estimates (by Tom Wangler) suggest that simulations with ~5 million macroparticles are sufficient for accurate beam loss estimates
- The IMPACT code presently achieves near-perfect scalability for RIA modeling. On 256 processors, full SC linac modeling with 5M particles will require ~50 min/simulation
- Without the factor of 256x speedup, a single such simulation would require 9 days!